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Evolution of Allowable Stresses in Shear for Lumber.

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Abstract

This paper surveys research leading to allowable shear stress parallel to grain for lumber. In early flexure tests of lumber, some pieces failed in shear. The estimated shear stress at time of failure was generally lower than shear strength measured on small, clear, straight-grained specimens. This and other engineering observations gave rise to adjustments that underwent some evolution not well described in the literature. Some anomalies which developed are discussed; an error is shown to have prevailed in the concept of a split beam for about 20 years. Some recent research done in Canada shows particular promise for describing the load capacity of checked beams that will fail in shear. This paper should provide helpful background for engineering groups charged with improving allowable property assignments for lumber and other wood products.

About the authors:

While this report was being compiled, three authors have moved from their Laboratory positions. Dr. Ethington is now Director of Forest Products and Engineering Research in the Washington office of the Forest Service. Montrey is with the Weyerhaeuser Company. Freas is retired.

EVOLUTION OF ALLOWABLE STRESSES IN SHEAR FOR LUMBER

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Introduction

Parallel-to-grain allowable shear stress for lumber has historically been viewed as less important than some other allowable properties and has probably been ignored in many design situations. With the advent of more thorough methods of analysis, computer designs, more complex structures, and composite products containing wood, engineers are taking a new look at allowable shear stresses. The National Forest Products Association's Committee on Research Evaluation has recently sought a complete review of them.

For all stress-grading methods currently in use, the allowable stress in shear is derived from shear tests of small, clear, straight-grained specimens of each species of interest. The shear strength reported for small specimens of clear wood is several times greater than the strength calculated from tests of large beams that fail in shear. This disparity has been the subject of scientific inquiry since about 1900, and attempts to explain it can be found in the literature. Early researchers were interested in establishing differences between results of the large test and the small test, but gave little attention to explaining reasons for the differences. (Knowledge of the differences would have been of benefit because the small test was clearly less expensive to perform.) Results of such early research are scattered and derivation of results not always well documented. This paper traces the developments that took place so far as the literature permits.

Throughout this paper, "shear factor" is defined as average shear strength from tests divided by allowable shear stress. Although typically the shear factor relates to tests of small, clear, straight-grained specimens, this was not always the case.

History of Allowable Shear Factors

Beginnings to 1933

By 1906 some tests of large timbers had been made and were reported by Hatt (13)[2], with small specimens taken from the failed pieces. A standard shear test had not been developed, but the origins of the present standard specimen (1) are apparent in Hatt's writing.

One of the initial research programs of the U.S. Forest Products Laboratory (FPL), beginning in 1910, was the evaluation of mechanical properties of small, clear, straight-grained specimens by species. In fact, some evaluations had been sponsored by the U.S. Government at several universities before 1910.

The researchers who had observed differences in shear strength (as well as in other properties) between small, clear specimens and full-size lumber must have sought explanations for the disparity. Also, Cline (9) by 1912 had speculated on the relationship between drying process and degree of checking.

As early as 1913, substantial amounts of clear wood data were available in USDA Forest Service Circular 213 (14), and many similar publications followed as additional data became available. The primary, and perhaps the only, major source of test results on large structural timbers was U.S. Forest Service Bulletin No. 108 (10), published in 1912. Although there had been earlier publications on this subject, Bulletin 108 appears to be a summary of all available data up to that time. It is cited in almost every document dealing with allowable stresses for lumber well into the 1930's.

Bulletin 108 gives data for the calculated shear stresses in structural beams which failed first in shear or in shear following another type of failure as well as for those which did not fail in shear. It also gives shear data from small, clear specimens cut from the structural members. The shear specimen used was different from that described in ASTM D-143 (1).

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[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2] Underlined numbers in parentheses refer to literature cited at end of this report.

Using data reported in Bulletin 108, the average shear strength of large beams that failed in shear can be compared with the strength of small, clear, shear specimens taken from the beams. Data are available for nine species, and the ratio of strength of small to large specimens ranges from 1.88 to 4.61 for green beams and from 2.57 to 4.12 for dry beams. These ratios would probably be different if the testing were done today because of changes in the small, clear, test specimen. (Data from small, clear specimens of green lumber in Bulletin 108 can be compared with those from the current Wood Handbook (26), and the modern averages are always higher than the earlier ones by from 7 to 36 percent.)

No additional basic data or studies have been found. Some later references cite the tests of large members of Bulletin 108; others cite clear wood averages which were changing with time as testing progressed.

By 1917, concern for translating the basic data to allowable properties for design appeared in the literature. Newlin and Wilson (25) stated without discussion that "only about one-eighth of the values given in the table for green material should be used as allowable stress in horizontal shear in beams. For small details, in timbers unaffected by shakes or checks, the allowable stress may be taken as one-fourth the value listed for green timber." Although it is not clear what was meant by "small details," Newlin and Wilson identified checks and shakes as being sufficiently more serious in large than in small timbers to suggest a different allowable stress. They did not explain their derivation of this value.

By 1919, with a book by Betts (8), tables of allowable stress properties began to appear in addition to, or instead of, tables of average strengths of small, clear specimens of lumber. These, too, tended to change fairly rapidly. For example, for what must have been approximately equivalent grades, refs. (8) in 1919 and (24) in 1923 showed the allowable shear stresses which are compared in table 1 of this paper.

Table 1.—Comparison of allowable shear stresses given in publications of circa 1920

Species	Source	
	Betts (8) (1919)	Newlin and Johnson (24) (1923)
	Lb/in.^{2}	*Lb/in.*^{2}
Douglas-fir		
Coast	95	90
Rocky Mountain	85	85
Pine, southern	125	110
Western hemlock	75	75
Western larch	100	100

Substantial test results on both large members and small specimens had accumulated by about 1920 and the relation between the strength of the two should have been quantified by that time. In fact, an important deduction can be made about the relation of small- to large-scale tests that has not been found stated in the literature. Ratios in the approximate range of 2½ to 3¼ can readily be worked out of tabulated results in such references as (9, 10, 14, 25). This must have been some of the least judgmental information then available, whereas the "shear factors" involved such judgments as "the reputation and behavior of the species in service."

It is clear that allowable values were both derived and recommended by FPL by 1925. Newlin (21) said in the published text of an address given in 1925, "it does not seem feasible to limit shakes and checks in large timbers as closely as knots or cross grain; therefore, to obtain a safe stress from tests of small, clear specimens it is necessary to use a factor one and one-half times as great for shear as for stress in the extreme fiber." Although (21) discusses the development of bending allowable stresses, the relationship of these stresses to bending tests of small, clear specimens is not explained. One can deduce that they probably were related by a factor of 320/81 and by a grade factor. According to the above quotation, the shear factor then should have been 160/27—that is, approximately 6—and a grade factor.

1933 to 1943

The decade of the 30's seems to contain more frequent reference to components of factors applied to clear wood average strength; however, the documentation for shear is particularly poor. Wangaard (29) collected information on the factors in use in the 1930's, but was able to uncover little regarding the shear factor other than that "a relatively high reduction factor, approximately 6 to 8, is used. . . ." Table 2 summarizes the only recorded components found. As R.P.A. Johnson was to write about this period later,[3] "No record was available, except for fiber stress in bending, on the exact numerical values assigned in the past to various factors as the result of the original analysis, on which present recommended stresses are based."

With the publication of a grading guide by Wilson (30) in 1934, the Forest Service ceased to recommend allowable properties and concentrated on grading principles. The development of grade descriptions and allowable properties was treated as the province of manufacturers and lumber specifiers. From then until about 1960, the Forest Service published basic stresses by species. No record was made of the basic stress derivation.

In a letter to A.R. Entrican of the New Zealand Forest Service dated September 19, 1933, Newlin describes the manner of arriving at allowable properties: "In addition to the tests on small, clear specimens of a species, tests on structural timbers influence our assignment of working stresses; the reputation and behavior of the species in service also were considered as well as the spread between the proportional limit and ultimate stress as determined by tests. And, finally, the rounding off of the values is to some extent a factor." It is clear from these statements that the general procedure was not necessarily one of applying a single shear factor to each species average obtained from small, clear specimens.

[3] From the unpublished record of 1943 FPL conference on working stresses for structural timbers.

Table 2.—Components of the shear factor as recorded in three early sources

Reference	Variability factor	Duration of load factor	Overload factor	Judgment factor	Concentration at bottom of checks
Newlin, 1925 (23)	—	—	—	3/2	—
Newlin, 1933[1]	4/3	16/9	3/2	—	9/4
Johnson, 1943[2]	4/3	16/9	9/8	—	9/4

[1] Letter to Mr. Alex R. Entrican, State Forest Service, New Zealand, dated Sept. 19, 1933.

[2] Unpublished record of 1943 conference on working stresses for structural timbers.

Elsewhere in the letter, Newlin specifically discusses the case of horizontal shear. "Our assigned stresses in horizontal shear are primarily the results of tests of structural timbers. A part of these bending tests was made on short, high stringers with symmetrical loads placed three to four times the height of the beams from the support. For such conditions we endeavor to have . . . a factor of about four for seasoned or treated stringers when placed in service. [Apparently, Newlin meant here that the exisiting practice was to assign an allowable stress that was one-fourth the average results from tests of structural timber.] To obtain these factors for a select grade stringer will require a factor of from 10 to 13 based on our standard shear test, depending upon the tendency of the species to develop shakes or checks. The following are the approximate factors that enter into this total factor: Variability 4/3, concentration of stresses at bottom of checks 9/4, grade 4/3, duration of stress 16/9, and the factor for overload 3/2. In addition, there should be applied a factor of ignorance where tests of small pieces only are available and also an additional factor for species known to develop shakes and checks."

The information in Newlin's letter to Entrican (1933) can be digested into a shear factor of 8 times a grade factor on a small, clear, straight-grained specimen basis, which seems to agree with the 1917 citation (25). However, Newlin's presentation at the 1925 ASCE meeting (21) had described a shear factor of 6 along with a grade factor (it is convenient here to keep the grade factor separate, since it obviously depends on the quality of individual pieces of lumber). In 1938, without explanation, Markwardt cited in an unpublished research memorandum a shear factor of 6.97 for softwoods, 7.52 for hardwoods. Thus, some evolution of factors is evident.

Newlin (21) and at least one other reference (24) suggest that a single early stress grade was conceived to have a grade factor of 4/3. Then (8)(4/3) = 10.7, which is in the range of 10 to 13 cited in Newlin's letter of 1933.

At this point a number of factors have emerged. Perhaps more important, the citations contain observations and rules-of-thumb that have been taken as axiomatic up to the present time. These key insights are tabulated below by date reported, which is probably long after the information was first put to use.

Date	**Concept**
1912	Shear strength of usable timber sizes is adversely affected by shakes, checks, and splits.
1917	Split-like defects may be enough different in large and small timbers to warrant different allowable shear stresses according to size.
1925	Split-like defects are difficult to control in graded lumber; therefore, the shear factor should be increased by 3/2.
1933	The shear factor need not be constant for all species.
1933	The initial judgments made in developing allowable shear stresses did not involve tests of small, clear, straight-grained specimens. Rather, a shear factor to be applied to large beam tests was developed.
1933	The shear factor can be thought of as a set of component factors, most of them attributable to measurable physical phenomena.

Newlin's letter of 1933 really suggested two shear factors and two methods for arriving at allowable stresses from experimental data: (1) from tests of large timbers and (2) from tests of small specimens. He suggested that performing both kinds of tests is preferred, but that either test can be used alone. If Newlin's thoughts are expressed in equation form, the allowable stress should be related to the average strength from a testing program as follows:

Average beam strength =
(4)(allowable stress) (a)
Average strength of small clear specimens =
(10 to 13)(allowable stress) (b)
Average strength of small, clear specimens =
(2½ to 3¼)(average beam strength) (c)

If the shear factor for either small or large specimens could be obtained, the other shear factor could be found by substitution into the above equations. The first such substitution arrived at was a shear factor to be applied to large beam test results, and Newlin's letter of 1933 established that it should be the 4 which appears in equation (a). We conclude that the development took place in the order (c), (a), (b).

In 1943, R.P.A. Johnson, formally addressing a conference held at FPL as a member of the U.S. War Production Board (WPB), cited a shear factor of 6.[3] He indicated that the WPB, lumber industry, and FPL agreed the shear factor could be decreased in keeping with war effort objectives by multiplying it by 5/6. Johnson's recommendation was corroborated by L.J. Markwardt in unpublished memoranda. Directive 29 of the WPB (28) suggests that such a change was officially made. This had the effect of changing the shear factor to 5.

1944 to the Present

After World War II, the WPB and all of its emergency regulatory powers disappeared. Notes from a National Lumber Manufacturers Association and FPL meeting held in 1948 demonstrate that there was considerable discussion about retaining the 5/6 change which had been dictated by the WPB. Shortly thereafter, FPL published new basic stresses (27) wherein the shear factor had been reduced by 10/11. FPL gave as the only reason an "exhaustive reevaluation of the original stress recommendations."

The lumber industry published new post-war allowable properties (19) and noted for the first time that 90 percent of the allowable values should be used for a load duration of "many years." Prior to that time, 100 percent had been recommended for permanent duration of load. (Duration of "normal" load was defined in 1948 as three years; the shift to a "normal" period of ten years came in 1951.) Thus, the 10/11 (approximately equal to 0.9) was treated as a shift in the intended load duration. However, this concept was not introduced into the standard for establishing structural grades until 1969 (3).

The present edition of ASTM D 245 (3) and all other editions since 1969 cite the shear factor for softwoods as 4.1, to be applied to the 5 percent exclusion limit for clear wood. This change—going from publishing basic stresses by species and species groups to a constant factor for hardwoods and one for softwoods—contradicted the early assumption that the factor should be different for each species based on the judgment of investigators. The factor is readily derived as

$$6(\tfrac{3}{4})(10/11) = 90/22$$

where

6 = the shear factor first cited by Johnson in 1943,

¾ = removal of the variability factor, which is handled by another method (2), and

10/11 = the post-World War II change, ostensibly from longtime to 10-year load duration.

Beginning with the 1957 edition of ASTM D 245, allowable shear stresses were effectively increased for 2-inch dimension lumber used in "light building construction" without defining this type of construction. A modified strength ratio concept was employed for splits and checks, based on the length of the defect rather than depth of penetration, and on the wide face width rather than the narrow face width. No corroborating evidence and no discussion of the change has been found; the Wood Handbook, 1955 edition, contains the same treatment.

Issues in Allowable Shear Property Development

Four issues in allowable shear development that were recurrently discussed over the years, and which have influenced present understanding of the subject, are as follows:

A. Complicating factors in allowable shear property calculation;

B. Adjustments for moisture content;

C. The so-called "two-beam theory;" and

D. Calculation of allowable shear in a split beam.

These issues are most clearly presented according to subject, rather than chronologically, in the following discussion.

Complicating Factors in Allowable Shear Property Calculation

Prior to 1920, the emphasis in testing clear wood specimens in shear was to *obtain data of the most immediate applicability*. For example, the relationship between large- and small-specimen tests was essential for setting allowable stresses for design. Until these primary issues were resolved, one would expect less attention to secondary or complicating factors for allowable shear. However, occasional attention was also paid to individual components of shear factors. A basic understanding of the role of complicating factors in shear stress derivation is apparent in a statement by Newlin (21) in 1925; he demonstrated that "working stresses" included factors for such things as variability, duration of load, checks, and "factor of safety" (i.e., judgment), although he did not specify the role of these complicating factors in shear stress derivation.

Variability

From the onset of the clear wood research program, an attention to variability was evident (7). Certainly from rather early on, there was enough information to demonstrate that the variability in clear wood shear strength was different from variability for modulus of rupture. When variability is discussed in the early literature, it is clear that variation in all properties had been observed, but typically a histogram of modulus of rupture for clear, green Sitka spruce is used as an example (see, for instance, (21), p. 401). Usually the accompanying text will simply state that a factor of 4/3 will "take care of variability."

By 1935, Markwardt and Wilson (18) had published evidence that the variability for shear is somewhat less than for modulus of rupture. Later, an effort was made to quantify variability; an unsigned memorandum among the records of a National Lumber Manufacturers Association Conference of 1948 notes that "This factor [variability] has been found to correspond to an exclusion limit of 5 percent for small, clear specimens."

Still later, the Wood Handbook (26) in the 1955 edition gives a coefficient of variation of 14 percent for shear strength and 16 percent for modulus of rupture. Despite this evidence, the 4/3 factor for variability appears to have been "borrowed" from bending strength observations.

Duration of Load

A similar "borrowing" of bending results probably occurred for duration of load effects. The early literature contains many observations such as that by Koehler (16) in 1919, "A beam kept loaded beyond the elastic limit will eventually break." The proportional limit was believed to be an index of acceptable behavior under long duration of load. Table 3 gives some values from the early literature, seen to be not greatly different from 1.78 (i.e., the 16/9 that appears in table 2). No records have been found of formal studies of duration of load in shear conducted in the United States prior to 1968 (12).

Checks

No evidence has been found to relate to the factor of 9/4 for "stress concentration at the bottom of checks" as described in Newlin's letter to Entrican (1933). Throughout the literature the concept appears as undocumented. However, E.G. King,

Table 3.—Proportional limit/modulus of rupture ratios for green wood as stated in 1935[1]

Species	Modulus of rupture in bending / Proportional limit in bending
Douglas-fir	
Coast	1.58
Rocky Mountain	1.78
Pine	
Longleaf	1.67
Shortleaf	1.87
Loblolly	1.78
Western hemlock	1.63
Western larch	1.80

[1] Data from ref. (18).

Assistant Vice President for Technical Services, National Forest Products Association, has suggested to us a plausible explanation. The 9/4 factor for checks was first found in print in 1933 (23). At about the same time, Newlin et al. (22) were studying checked beams intensively. In some artificially checked beams they reported shear strength about 4/9 of the strength of unchecked beams.

"Factor of Safety"

The overload factor is, of course, purely a judgment. It is sometimes referred to in the literature by other names, such as "factor of safety." In 1924, Newlin and Johnson discussed the factor of safety in unpublished records of research as having two components. One of these, they said, was to take care of characteristic differences in the strength of wood; the other ". . . to the care of overloading and such other factors necessary for the safety of the structure."

Twenty years later, this factor was defined in more detail, suggesting a greater understanding; in 1943,[3] Johnson credited the overload factor (by then, 9/8) with accounting for ring angle, seasoning, fabrication errors, and offsize.

Adjustment for Moisture Content

Early recommended grading rules such as Newlin's and Johnson's of 1928 (24) apparently did not allow an increase for drying. These rules included a working stress in shear said to be valid for all locations of use; no basis for the rules was discussed. This philosophy of a single allowable stress despite moisture content still prevailed in 1934 with the publication of a grading guide by T.R.C. Wilson (30).

Attitudes behind the grading rules are better understood by reviewing the many editions of ASTM D 245 (3). ASTM D 245-30, the 1930 edition, is quite specific and clear regarding shear, but changes are made in subsequent editions with decreasing amounts of explanation. The 1930 edition states, "shake in green material is assumed to reduce shearing stress in direct proportion to its extent. A greater amount of shakes is permitted in seasoned material, made up for by the increased resistance of the remaining cross-section when seasoned." The exact rules relating size of shakes and similar permissible defects to the fractional strength of green, clear wood are stipulated in the text, expressed as formulas, and also graphed (See Appendix). In this rather all-inclusive edition, basic stresses by species are tabulated and grades are described with allowable properties. The properties are given for three different moisture conditions, but for each case the shear stress is the value in the green condition.

Thus the concept was that, for a species and grade, there was only one allowable shear for all moisture conditions. However, in the grading process, a larger shake was permitted for lumber graded dry than for lumber graded green. The shear strength of the wood was expected to increase enough upon drying to offset the fact that shakes would lengthen.

By the 1949 edition, dramatic changes in format had taken place. Two separate strength ratio tables for shear were given, one for green lumber and one for dry lumber. The strength ratios for green lumber are the same as those given in the 1930 edition for all moisture contents. The strength ratios for dry lumber are 9/8 of those for green lumber. The same 9/8 ratio appears in (30), dated 1934. This 9/8 ratio has in (30), however, the effect of providing for the first time a higher allowable shear stress for lumber graded dry than for lumber graded green.

Footnote b of table X in the 1949 edition of ASTM D 245 (3) states: "Modification for seasoning in current commercial practice is accomplished by liberalizing defects in grade rather than increasing working stress." In the 1957 edition this footnote has become "Modification for seasoning in joists and planks may be accomplished either by liberalizing grade limitations or by increasing working stress." In the 1969 edition of D 245, the footnote has disappeared as has the strength ratio table for dry lumber. The 9/8 seasoning adjustment is retained, but applies only to lumber dry at time of manufacture (i.e., dried before grading).

In this same 1969 edition of D 245, the paragraph still remains which permits larger shakes in dry lumber than in green.[4] This paragraph is notable because it provides for the first time a "double advantage" for dry lumber—both larger shakes and an increase in allowable shear stress. Double advantage is resolved in the extensively revised 1970 version where the reference to different shake limitations for green lumber and dry lumber is eliminated.

To summarize, the earliest procedure controlling splits—introduced in 1925—was to impose no control over split-like defects in grading, but instead to increase the shear factor by 3/2 to account for their probable deleterious effect. Shortly thereafter, in 1934, it was assumed that allowable shear stress for green lumber was also valid for dry lumber, but dry lumber was permitted larger defects to compensate partly for the increased shear factor. By 1949, a one-eighth increase in shear for dry lumber was offered as an alternative, but only if the lumber was dry when graded. No records have been located in support of these changes.

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[4] ASTM D 245-69, paragraph 16.1, which actually originated in D 245-30. However, the specified size increase for seasoning in joist and plank in earlier editions no longer appears (See Appendix).

The Two-Beam Theory

The design of checked beams has historically been based on the 1934 recommendations of Newlin, Heck, and March (22). Their work, which introduced the so-called "two-beam action" concept, demonstrated that the stresses in checked beams cannot be adequately described by the familiar elementary formula for horizontal shear. It is claimed in (22) that, due to checking, the beam's behavior is more like that of two nearly independent beams.[5] The most severe location for application of a single concentrated load on a side-checked beam is asserted to be at a distance from the support equal to three times the beam depth (conventionally, the most severe location is at the support). Based on the analytical derivations, the shear stress at the neutral axis at this critical location in the checked beam is found to be 10/11 of that given by the familiar formula for an unchecked beam and is a larger fraction than at any point closer to the support. The implication is that the beam has a greater load-carrying capacity if it is checked than if it is not, presumably due to redistribution of stresses—an implausible conclusion.

Although the two-beam theory does provide useful qualitative insights, it cannot be expected to provide accurate quantitative results due to limitations within the analysis. Essentially, it is an elastic analysis of an isotropic material which purports to describe an inelastic phenomenon involving an orthotropic material. The analysis is mandated by assumption to yield results which are independent of check depth. Also, because the theory treats only checks which occur along the entire span length, it does not present the designer or formulator of grading rules with much flexibility in treating less severe situations. The conclusion regarding the most severe location for a single concentrated load results from experimental data, yet subsequent work by Newlin (20) shows that this location can be derived entirely analytically, and that it depends explicitly on the beam span/depth ratio. Additionally, an energy minimization procedure described by C.B. Norris in research notes (1962) leads to expressions which are not in complete agreement with analogous results from the two-beam theory.

These shortcomings of the two-beam theory must be rectified. Currently accepted design procedures for checked beams are all based on this theory, providing motivation for development of a new approach to shear design. The fracture mechanics approaches of J.D. Barrett and R.O. Foschi offer a promising methodology for treating this field. These researchers have developed a technique (11) relating the shear strength of clear beams to the shear strength experimentally determined from small specimens according to established ASTM standard testing procedures. They have also proposed criteria (5,6) for the strength of end-cracked (i.e., checked) beams in terms of a shear-governed critical stress intensity factor, calculated using fracture mechanics and related to external loading. This methodology holds considerable promise of providing the technical source for new, more rational criteria for shear design.

The Split Beam

The 1976 edition of ASTM D 245 states in paragraph 4.2.3, "Strength ratios below 50 percent are not used, because a bending member that is split completely through lengthwise will still hold one-half the shear load of an unsplit member." A review of this statement, using the horizontal shear formula, will demonstrate it to be incorrect. The split member (assuming it homogeneous with respect to shear strength) will support the same shear load as before it split.

To understand the error, it is instructive to review previous editions of the standard and to consider other documents. Prior to 1957, the subject was not broached in ASTM D 245. The versions of the standard from 1957 to 1969 state: "The maximum effect from shakes is to reduce the strength by half, since a piece split completely in two has half the strength that it would have if no shake were present."

The 1957-69 wording was probably badly chosen. Since the "strength" is a characteristic of the wood, "load capacity" was probably intended. Once the member has split, the load capacity can be diminished for reasons not apparent in the horizontal shear formula. The most obvious reasons are excessive deflection and excessive flexure stress. Deflection has traditionally not been of much concern in allowable property development, so flexure stress is a likely candidate. It can readily be shown from the flexure formula that the moment capacity of a beam split in half (treated as two beams acting independently) is one-half the moment capacity of the unsplit beam.

It seems probable that the 1957 authors meant "The maximum effect from shakes is to reduce the load capacity by half, since a piece split completely in two can support half the moment that it would if no shake were present." The concept is not new, and is woven through earlier documents reviewed. For example, Newlin and Johnson wrote in 1924 in an unpublished memorandum, "After failing in shear, . . . timbers can usually carry their design load with safety because of their high bending strength."

Closing Commentary

This paper ties together bits of historical evidence on the development of allowable shear stresses for lumber as they presently exist in the United States. No obvious and dramatic flaws in the development of presently held concepts are apparent except for the split-beam concept expressed in ASTM D 245. However, the historical review presented here should aid engineering groups charged with bringing about improvements in allowable property assignments for lumber. It may also help to focus attention on similar developments for other traditional structural wood products.

Readers of this paper have doubtless noticed the need to rely on unpublished letters, memoranda, and notes—or even inferences—to fill gaps in the history of shear factors. The paucity of documented information is in striking contrast to the importance of the subject to current engineering practice. Irregular records in this area should serve to stress the importance of systematic and accessible publication of research. Furthermore, the history of important developments in engineering should be written—including the background to important committee decisions—while such records as exist are yet accessible and while pioneer researchers are still available to fill in the story. Recent ASTM instructions dealing with the preparation of standards emphasize this type of documentation (4): One of the "standards of due process" in preparation of a voluntary standard is "maintenance of adequate records of discussions and decisions."

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[5] This research dealt only with beams containing side checks running the length of the beam. However, the results have been used for beams with end checks across the width and even for unchecked beams.

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APPENDIX

Procedures for Handling Allowable Shear in ASTM D 245: A Chronology

This appendix highlights certain steps in the development of ASTM D 245 through reprinting key excerpts that deal with allowable shear. These excerpts serve to complement the text of this paper, which has discussed in a more general way the historical development of design properties for shear and the factors employed as adjustments. The text considers, in particular, the application of research to key decisions that were reflected in grading rules or design recommendations. These decisions, in most cases, were also reflected in the wording of ASTM standard D 245 and supporting documents. Note that the evolution of D 245 from 1927 onward parallels the dramatic development of a national uniformity in lumber-grading practices. The writers of D 245 reflected the perception and practice of their era in the standard. (The impact of the "split-beam concept," for example, became visible in D 245-57T, paragraph 27.)

It is virtually impossible to summarize the stages in the development of ASTM D 245 with complete clarity. Format, intent, and content of this standard have changed markedly since the first edition in 1927.

Thus it is extremely difficult to present from the many editions of D 245 a sequence of corresponding paragraphs that treat of exactly the same subject (e.g., measuring size of splits). This appendix attempts a useful but admittedly incomplete highlighting of topics necessarily dealt with in the many editions of ASTM D 245: (a) means of measuring shakes, checks, and splits; (b) size of the shakes, checks, and splits permitted; (c) strength ratio and allowable property derivation procedures; and (d) special rules for lumber used in light framing. Other elements of the history, such as adjustment factors, are not covered completely here. Also, excepting (d), quotations chosen from D 245 relate principally to joists and planks; quotations dealing with other lumber categories are usually omitted.

Topics (a) through (d), although necessarily addressed in all versions of D 245, were not always clearly segregated as in this appendix. In fact, historical study of D 245 is difficult because, early in the development of the standard, actual grade descriptions were included. Later, the grade descriptions were dropped, but the concern for detailed examples of grading practice and for tabulation of stress values by species persisted until after World War II. Later (1969), clear wood values were placed in D 2555 (2) and examples were restricted.

Procedural Changes

D 245 moved quickly from general statements on shear in 1927 to graphs relating shake size to strength reduction in 1930. Significantly, in 1937 the standard handled shear allowables by reference to USDA Miscellaneous Publication 185 (30). Strength ratio tables then appeared in the standard in 1949 and have been used ever since. The strength ratio formula for shear changed in D 245-69.

Procedures for calculating the size of checks and splits in the field has varied over the years but the standard has consistently referenced checks and splits to shakes. The basic reference of calculating the size of a shake relative to lines parallel to the wide face has persisted from 1927.

Editorial Changes

Editorially, D 245 has been revised toward more logical arrangement. Drastic changes in format and organization took place between 1927 and 1939; the format introduced for commentary in 1939 will appear familiar to present readers. The most recent major editorial changes were made in 1974.

The difficulty with early editions of finding logically related passages in different parts of the standard—all needed to understand the procedure for limiting characteristics and calculating allowable properties—has largely been remedied in the latest editions.

Presentational Scheme

A series of excerpts from D 245 follow, arranged by subtopic and by year. However, because the excerpts generally are found scattered throughout the standard rather than adjacent as they appear here, paragraph numbers and page numbers are included for those who may wish to refer back to the several editions.

The four subtopics referenced are as follows:

Means of measuring shakes, checks, and splits.
Size of the shakes, checks, and splits permitted.
Strength ratio and allowable property derivation procedures.
Special rules for lumber used in light framing.

Interjected commentary by the authors is within square brackets. Sections which have not changed significantly from the previous edition are so indicated, and are not reprinted.

In some instances, the year in which a standard was formally approved may not be the same year that it appeared in an ASTM edition. For the headings below, the year of approval follows the standard's number, and the year it first appeared as part of the annual books of ASTM standards follows in parentheses. Thus, for D 245-70 (1971), approval was in 1970, but it first appeared in the Annual Book of Standards in 1971. Standards which contain a "T" in the title were designated by the ASTM as "tentative;" this designation is no longer used.

Size of the Shakes, Checks, and Splits Permitted

D 245-27 (1927)

17. Shakes reduce the area of a beam acting in resistance to shear, and the limitations placed on shakes are based on this reduction. Checks are limited on the same basis as shakes, and no combination of shakes and checks is permitted which would reduce strength to a greater extent than would the allowable size of either separately.

18. Shakes and checks in Dense Select and Select joist and plank shall not exceed when green one-fourth the width of end nor when seasoned one-third the width of end.

Shakes and checks in Common joist and plank shall not exceed when green four-tenths the width of end nor when seasoned four-ninths the width of end. [p. 583]

[The following is an essential commentary in the 1927 D 245:]

32. The following rules for Structural Grades conform to the "Basic Provisions for the Selection and Inspection of Softwood Dimension and Timbers Where Working Stresses are Required" accepted at the General Lumber Conference, Washington, D.C., May 1, 1925, as the basis for the preparation of grading rules for structural material. [p. 585]

D 245-30 (1930)

A greater amount of shakes is permitted in seasoned timber, made up for by the increased resistance of the remaining cross-section when seasoned. In green material, shakes are permitted in direct proportion of increase from none in a grade of the strength of green, clear wood to one-half the width of the piece in a grade having one-half the strength of green, clear wood. In seasoned material, shakes are similarly permitted from one-ninth the width of the piece in a grade of the strength of green, clear wood to five-ninths the width of the piece in a grade having one-half the strength of green, clear wood. (See sections 24 and 25 under A. Structural Grades of Lumber and Timber and the Method of Their Derivation.) [Explanation for Plate II, Fig. 7, p. 811-812]

24. Shakes reduce the area of a beam acting in resistance to shear, and the limitations placed on shake in such material are based on this reduction. Checks are limited on the same basis as shakes, and no combination of shakes and checks is permitted which would reduce strength to a greater extent than would the allowable size of either separately. Shake in green material is assumed to reduce shearing stress in direct proportion to its extent. A greater amount of shake is permitted in seasoned material, made up for by the increased resistance of the remaining *cross-section when seasoned.* [p. 756-757]

25. In joist and plank, and beams and stringers, shake in green material is permitted in direct proportion of increase from none in a grade of the strength of green, clear wood to one-half the width of the piece in a grade having one-half the strength of green, clear wood. In seasoned material, shake is similarly permitted from one-ninth the *width of the piece in a grade of the* strength of green, clear wood to five-ninths the width of the piece in a grade having one-half the strength of green, clear wood. [p.757]

D 245-33 (1933)

[Wording of par. 24 and 25 of D 245-30 retained in par. 24 and 25 of D 245-33, p. 349.]

D 245-37 (1939)

[No general restrictions are noted. Restrictions are by specific grades, sizes, and species and stem from USDA Miscellaneous Publication No. 185.]

D 245-49T (1949)

[Par. 12(a) same as par. 24, D 245-30. Par. 12(b) is the same as par. 25 D 245-30.]

Modification for seasoning in current commercial practice is accomplished by liberalizing defects in grade rather than increasing working stress. [Footnote b of Table X, p. 613]

D 245-57T (1958)

[Par. 12(a) and (b) of D 245-49T become par. 16(a) and (b) of D 245-57T except the term "thickness" replaces "width"; the following one sentence is added to (b), and also par. (c) is added:]

The maximum effect from shakes is to reduce the strength by half, since a piece split completely in two has half the strength that it would have if no shake were present.

(c) Since shear stress in most joists or beams is greatest near the ends, the restrictions are applied only for a distance from each end equal to three *times the height of the piece. (Height equals width of wide face.)* Since shear stress is greatest near the neutral axis, the restrictions also are applied only in the middle one half of the height of the piece; and only the shakes, checks, and splits in this section are measured.

[Footnote b of Table X, D 245-49T is now footnote b of Table IX and modified as follows:]

. . . accomplished either by *liberalizing grade limitations or by* increasing working stress. [p. 213]

D 245-69 (1969)

[Par. 16 (a), (b), and (c) of D 245-57T as 16.1, 16.2, and 16.3, except that in 16.2 for joist and plank, shake permitted is related to grade only on the basis of green condition. p. 159]

[Footnote b of table IX, D 245-57T, no longer appears.]

D 245-70 (1971)

4.4.3 In single-span bending members, shakes, checks, and splits *are restricted only for a distance from* each end equal to three times the width of the wide face, and within the critical zone, only in the middle one half of the wide face. For multiple-span bending members, shakes, checks, and splits are restricted throughout the length in the middle one half of the wide face.

4.4.4 Outside the critical zone in bending members, and in axially loaded members, shakes, checks, and splits have little or no effect on strength properties and are not restricted for that reason. It may be advisable to limit them in some applications for appearance purposes, or to prevent moisture entry and subsequent decay [pg. 149]

D 245-74 (1975)

[No significant change from D 245-70.]

Means of Measuring Shakes, Checks, and Splits

D 245-27 (1927)

3(b). Shake shall be measured on the ends of a piece, and its size shall be taken as the shortest distance between lines enclosing the shake and parallel to the wide faces of the piece. Checks and splits shall be limited as provided for shakes. [p. 587]

D 245-30 (1930)

[The essential elements of shake, check, and split measurement of D 245-27 were maintained in par. 6(b), p. 761, and par. 16, p. 766.]

D 245-33 (1933)

[Essential wording of D 245-30 retained.]

D 245-37 (1939)

10. (a) Shakes, checks, and splits, when permitted in the grade specified later in these specifications, shall be measured at the ends of the piece. Only those within the middle half of the height shall be considered. (The height equals the width of the wide face.) Size of shake is the distance between the lines enclosing the shake and parallel to the wide faces of the piece. Permissible size is determined by the width of the narrow face of the piece.

(b) Checks and splits shall be measured and limited in the same way as shakes. The following limitations apply to both ends but only within the middle half of the height of the piece and within three times the height from the end. (The height equals the width of the wide face.) Size of checks within this portion of the piece shall be taken as their estimated area, along the horizontal section showing maximum area, divided by three times the height of the piece (Note). When checks on two parallel faces are opposite or approximately so, the sum of their sizes shall be taken. The sum of sizes of shakes, checks, and/or splits shall not exceed the permissible size of shake.

(c) Checks extending entirely across the end within the middle half of the height shall not extend into the piece at the center of width of end a distance greater than the size of the allowable shake.

Note.—A practical method of inspection in the field to determine the size of checks and splits under the above specification is as follows:

The size of checks within the specified portion of the piece shall be taken as the sum of seven depth measurements, one on the end and three on each side, divided by three. Each measurement shall represent the greatest depth of any check within the center half of the height; the measurement on the end shall be taken at the center of the width, and the three measurements on each side shall be taken at distances of one, two, and three times the height of the piece from the end in joist, plank, beams and stringers, and the width of the piece from the end in posts and timbers. Each measurement shall be determined by penetration into the piece of a probe 1/64 inch in thickness and 1/4 inch in width. [p. 495]

D 245-49T (1949)

[Par. 44 (g) and (o) of D 245-49T, p. 608, retains the same wording as par. 10 of D 245-37 except that the note included under 10(c) is omitted.]

D 245-57T (1958)

38. (a) Shakes are measured at the ends of the piece, and the size permitted is determined by the thickness of the piece. The size of a shake is the distance between lines enclosing the shake and parallel to the wide faces of the piece.

(b) Checks and splits are limited to the same nominal dimensions as shakes (Table V) but are measured differently. The size of a check is its average depth of penetration into the piece measured from the perpendicular to the surface of the wide face. The size of an end split is one third of its average length.

(c) The grading of any combination of shakes, checks, and splits in the middle one-half of the height is based on the grader's judgment of the probable effects of seasoning or loading in service on the combination. Where a combination of two checks in opposite faces, a check and a split, a check and a shake, or a split and a shake may later become a single horizontal shear plane, the sum of the sizes in the combination is restricted to the allowable size of shake. Where such a combination is not additive in this way, only the largest single characteristic is considered. [p. 203]

D 245-69 (1969)

[Par. 38(a)(b)(c) of D 245-57T is repeated as par. 36.1 through 36.3 in D 245-69 p. 172.]

D 245-70 (1971)

[Essential elements in pars. 4.4.1, 4.4.2, and 4.4.5, p. 148, are the same as D 245-57T, pars. 38(a), (b), and (c) except notion of "equivalent shakes" is introduced for splits and checks and "middle one-half of height" is dropped as a qualifying statement from combination of characteristics in par. 4.4.5]

D 245-74 (1975)

[No significant change from D 245-70.]

Strength Ratio and Allowable Property Derivation Procedures

D 245-27 (1927)

5. Working values given for horizontal shear are maximum values. The maximum unit horizontal shear at any point in a beam as calculated is one and one-half of the average unit shear obtained by dividing the total shear at that point by the area of the cross-section. [p. 611]

25. Working stresses in shear are not varied with size or extent of exposure . . . [p. 617]

D 245-30 (1930)

[Par. 5 of D 245-27 repeated as par. 17, p. 797 plus the following:]

17 . . . To get the total safe shearing stress at any cross-section, the area of the cross-section should be multiplied by two-thirds the maximum allowable

horizontal shear. To obtain the required area to carry any given shear, the total shear should be divided by two-thirds the maximum allowable unit shear. [p. 797]

[Par. 25, p. 617 of D 245-27 repeated as par. 10, p. 793.]

In joists and beams, shakes in green timber is assumed to reduce shearing stress in direct proportion to its extent. [p. 811]

[For further clarification of the 1930 relation of shakes and checks to strength, see our reproduction of "Plate II."]

[An essential part of D 245-30 was an appendix entitled, "Working Stresses—Notes on Working Stresses for Structural Grades of American Lumber Standards." In addition to the above sections which were in this Appendix, the following table and footnote relate directly to shear:]

Table I. Basic Working Stresses for Green, Clear Wood of Structural Sizes To which grade-strength ratios can be applied to determine working stresses for grades containing defects. Stresses in . . . horizontal shear, are varied with grade. Stresses in horizontal shear . . . are not varied with exposure. [A table of basic stresses *follows*. p. 792]

[1] These data are published as the result of cooperative work by several organizations including the U.S. Forest Products Laboratory, the American Railway Engineering Association, and the ASTM. They do not form a part of the specifications as a purchase specification. They are printed with the specifications as a convenience to the user so that the data will be immediately available without further reference. [Footnote to appendix, p 791]

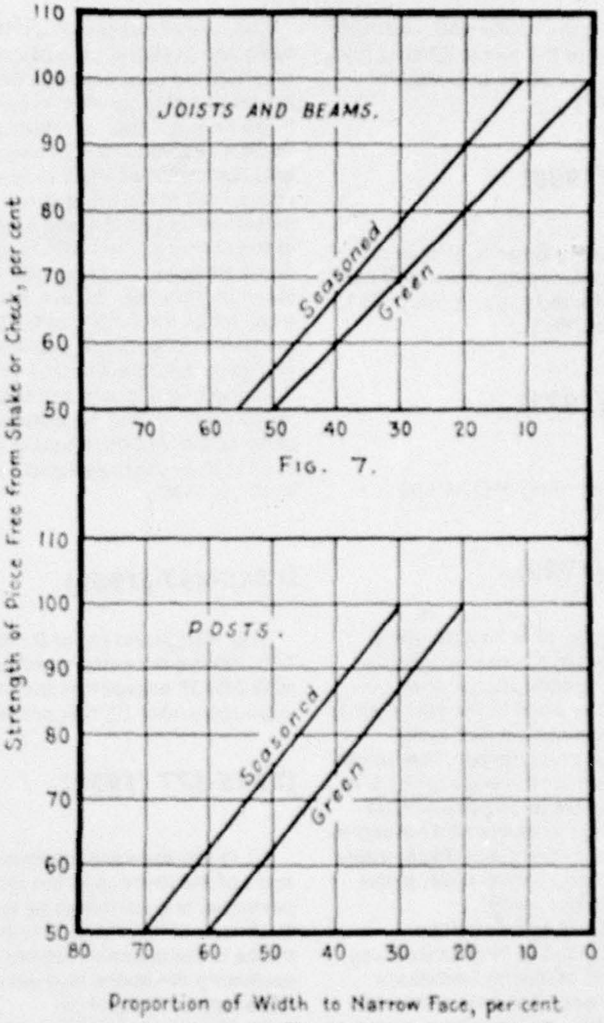

FIG. 7.

FIG. 8.

PLATE II.—Relation of Shakes and Checks to Strength.

D 245-33 (1933)

[Appendix of D 245-30 retained, p. 384.]

D 245-37 (1939)

[The following are explanatory notes. No other information on stresses was provided in D 245-37.]

Prior to their present adoption as standard, these specifications were published as tentative from 1926 to 1927, being revised in 1927. They were adopted in 1927, revised in 1929, 1930, and 1933, but withdrawn and republished as tentative from 1936 to 1937. Editorially revised and rearranged in 1939. [Footnote, p. 494]

The detailed reasoning basic to these grades will be found by a study of a report of the U.S. Forest Products Laboratory, U.S. Department of Agriculture Miscellaneous Publication No. 185, entitled "Guide to the Grading of Structural Timbers and the Determination of Working Stresses," February, 1934. Reference should also be made to the "Working Stresses" appearing in the Appendix to the Standard Specifications for Structural Wood Joist and Plank, Beams and Stringers, and Posts and Timbers (ASTM Designation: D 245 33) of the American Society for Testing Materials, 1933 Book of ASTM Standards, Part II, p. 384. [p. 512]

D 245-49T (1949)

Strength Ratio and Working Stress[1]

18. (*a*) The strength ratio of a grade represents the remaining strength after making allowance for the maximum effect of the permitted knots. . . .

(b) Working stresses for any grade of

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[1] [Much of this wording is from Misc. Pub. No. 185 (27). There are, however, some additions and deletions in this D 245 version.]

structural lumber are found by multiplying the strength ratio by the basic stress. Basic stress is a generalized working strength value for the clear wood . . .

(c) . . . whereas shearing stress depends on shakes and checks. Consequently, strength ratios for shear and for stress in extreme fiber may differ in the same grade, and a ratio for each kind of stress is necessary to characterize a grade . . .

(d) Economy may be served by specifying these ratios in such relation to each other that the allowable working stresses for shear and for extreme fiber will be in balance . . . [p. 596]

[For clarification of strength ratio calculations, see the abridged reproduction of the 1949 "Table V."]

D 245-57T (1958)

[The following sentence was added to par. 16(b)]

The maximum effect from shakes is to reduce the strength by half, since a piece split completely in two has half the strength that it would have if no shake were present. [p. 192]

[Par. 23(a)-(d) essentially the same as D 245-49T par. 18; par. (e) added:]

23. **(e) Strength ratios are applied stresses in transverse bending, tension parallel to grain, compression parallel to grain, and horizontal shear in beam. Modulus of elasticity and compression perpendicular to grain are little affected by strength-reducing characteristics, and strength ratios of 100 percent are assumed for all grades.** [p. 194]

TABLE V.—STRENGTH RATIOS CORRESPONDING TO VARIOUS COMBINATIONS OF SIZE OF SHAKE AND WIDTH OF END OF PIECE.

Beams and Stringers........................
Joists and Planks........................ {Strength Ratios for Stress in Horizontal Shear

Size of Shake, in.	Section A.—Green Lumber[a]										Section B.—Seasoned Lumber[b]									
	Percentage Strength Ratios for Nominal End Width of Piece in Inches Indicated										Percentage Strength Ratios for Nominal End Width of Piece in Inches Indicated									
	2	3	4	5	6	8	10	12	14	16	2	3	4	5	6	8	10	12	14	16
¼........	90	93	95	96	96	97	98	98	98	99	100	100	100	100	100	100	100	100	100	100
⅜........	83	89	92	93	94	96	97	97	98	98	94	100	100	100	100	100	100	100	100	100
½........	77	85	88	91	92	94	95	96	97	97	87	95	100	100	100	100	100	100	100	100
⅝........	71	81	85	88	90	93	94	95	96	96	80	91	96	99	100	100	100	100	100	100
¾........	65	76	82	86	88	91	93	94	95	96	73	86	93	97	99	100	100	100	100	100
⅞........	58	72	79	83	86	90	92	93	94	95	66	81	89	94	97	100	100	100	100	100
1........	52	68	76	81	84	88	90	92	93	94	59	77	85	91	94	99	100	100	100	100
1⅛........	46	64	73	78	82	86	89	91	92	93	52	72	82	88	92	97	100	100	100	100
1¼........	26	60	70	76	80	85	88	90	91	92	45	67	78	85	90	95	99	100	100	100
1⅜........	...	56	67	73	78	83	87	89	90	92	20	62	75	82	87	94	97	100	100	100
1½........	...	51	63	71	76	82	85	88	90	91	...	58	71	80	85	92	96	99	100	100
1⅝........	...	47	60	68	74	80	84	87	89	90	...	53	68	77	83	90	95	98	100	100
1¾........	...	35	57	66	71	79	83	86	88	[c]	...	48	64	74	80	88	93	96	99	100
6¼........	...	...	...	...	...	...	...	...	[illegible]	[illegible]	...	...	...	...	...	...	...	[illegible]	[illegible]	
6½........	...	...	...	...	...	...	...	...	54	66	...	...	...	...	...	...	...	52	61	67
6¾........	...	...	...	...	...	...	...	...	52	58	...	...	...	...	...	...	...	50	59	65
7........	...	...	...	...	...	...	...	...	50	56	...	...	...	...	...	...	...	...	57	64
7¼........	...	...	...	...	...	...	...	...	...	55	...	...	...	...	...	...	...	...	55	62
7½........	...	...	...	...	...	...	...	...	...	53	...	...	...	...	...	...	...	...	53	60
7¾........	...	...	...	...	...	...	...	...	...	52	...	...	...	...	...	...	...	...	51	58
8........	...	...	...	...	...	...	...	...	...	50	...	...	...	...	...	...	...	...	...	56
8¼........	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	55
8½........	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	53
8¾........	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	51
9........	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	49

[a] Values in Section A of Table V are found from the following equation: $S = \frac{100 - R}{100}$, where R is the strength ratio in per cent and S is the permissible size of shake stated as a fraction of the width of the end of the piece. Where strength ratios are 45 per cent or higher, the nominal width is used in calculation; for lower strength ratios, the actual width is used.

[b] Values in Section B of Table V are found from the following equation: $S = \frac{900 - 8R}{900}$, where R is the strength ratio in per cent and S is the permissible size of shake stated as a fraction of the width of the end of the piece. Where strength ratios are 45 per cent or higher, the nominal width is used in calculation; for lower strength ratios, the actual width is used.

[c] Ratios for sizes of shake other than those listed between 3 and 9 in. can be found by interpolation.

27. Strength ratios for various combinations of thickness of piece with size of shakes, checks, or splits are given in Table V. The table is in two sections, one for green and the other for seasoned lumber. Values for green lumber are found from the equation

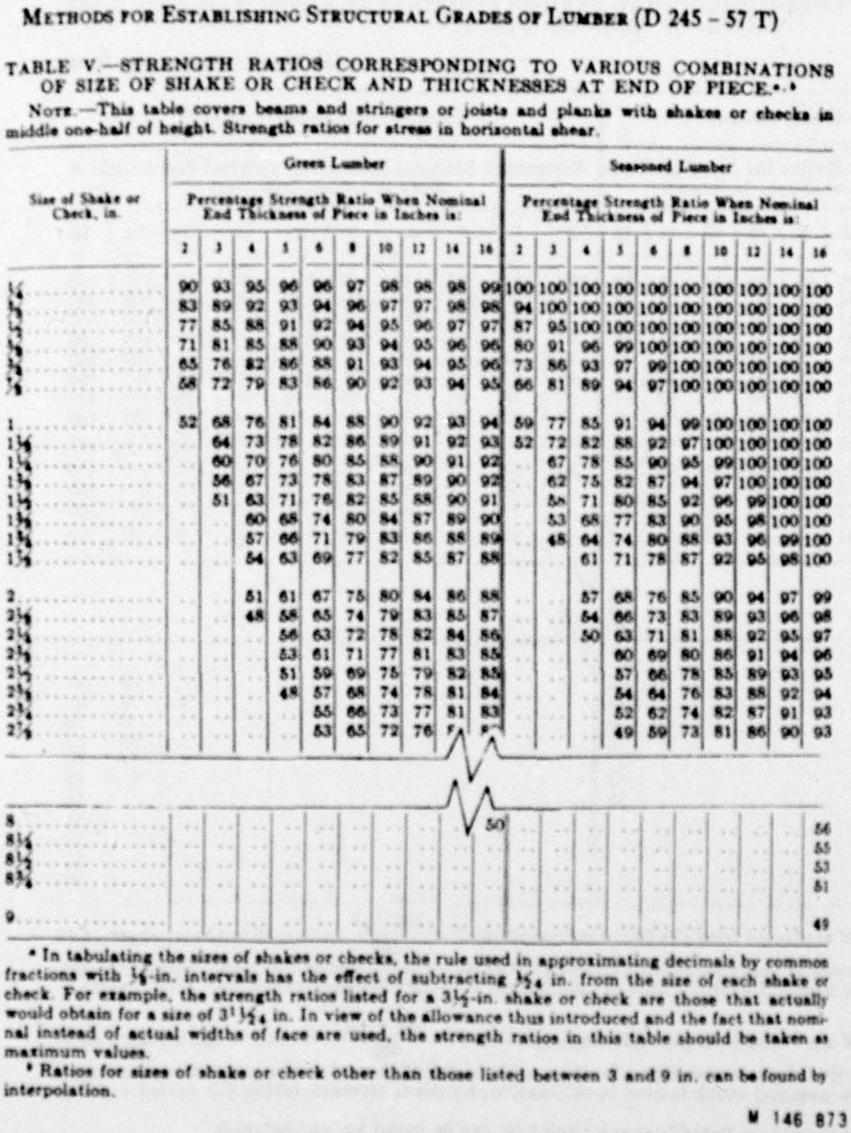
$$S = \frac{100 - R}{100}$$

and values for seasoned lumber from the equation

$$S = \frac{900 - 8R}{900}$$

where R is the strength ratio in percent, and S is the permissible size of shake, check, or split, stated as a fraction of the thickness at the end of the piece. Strength ratios below 50 percent are not used (Section 16(b)).[p. 195]

[Note the 1958 version of "Table V," abridged here.]



METHODS FOR ESTABLISHING STRUCTURAL GRADES OF LUMBER (D 245 - 57 T)

TABLE V.—STRENGTH RATIOS CORRESPONDING TO VARIOUS COMBINATIONS OF SIZE OF SHAKE OR CHECK AND THICKNESSES AT END OF PIECE.[a, b]

NOTE.—This table covers beams and stringers or joists and planks with shakes or checks in middle one-half of height. Strength ratios for stress in horizontal shear.

Size of Shake or Check, in.	Green Lumber										Seasoned Lumber									
	Percentage Strength Ratio When Nominal End Thickness of Piece in Inches is:										Percentage Strength Ratio When Nominal End Thickness of Piece in Inches is:									
	2	3	4	5	6	8	10	12	14	16	2	3	4	5	6	8	10	12	14	16
1/4	90	93	95	96	96	97	98	98	98	99	100	100	100	100	100	100	100	100	100	100
3/8	83	89	92	93	94	96	97	97	98	98	94	100	100	100	100	100	100	100	100	100
1/2	77	85	88	91	92	94	95	96	97	97	87	95	100	100	100	100	100	100	100	100
5/8	71	81	85	88	90	93	94	95	96	96	80	91	96	99	100	100	100	100	100	100
3/4	65	76	82	86	88	91	93	94	95	96	73	86	93	97	99	100	100	100	100	100
7/8	58	72	79	83	86	90	92	93	94	95	66	81	89	94	97	100	100	100	100	100
1	52	68	76	81	84	88	90	92	93	94	59	77	85	91	94	99	100	100	100	100
1 1/8	..	64	73	78	82	86	89	91	92	93	52	72	82	88	92	97	100	100	100	100
1 1/4	..	60	70	76	80	85	88	90	91	92	..	67	78	85	90	95	99	100	100	100
1 3/8	..	56	67	73	78	83	87	89	90	92	..	62	75	82	87	94	97	100	100	100
1 1/2	..	51	63	71	76	82	85	88	90	91	..	58	71	80	85	92	96	99	100	100
1 5/8	..	..	60	68	74	80	84	87	89	90	..	53	68	77	83	90	95	98	100	100
1 3/4	..	..	57	66	71	79	83	86	88	89	..	48	64	74	80	88	93	96	99	100
1 7/8	..	..	54	63	69	77	82	85	87	88	..	..	61	71	78	87	92	95	98	100
2	..	..	51	61	67	75	80	84	86	88	..	..	57	68	76	85	90	94	97	99
2 1/8	..	..	48	58	65	74	79	83	85	87	..	..	54	66	73	83	89	93	96	98
2 1/4	..	..	..	56	63	72	78	82	84	86	..	..	50	63	71	81	88	92	95	97
2 3/8	..	..	..	53	61	71	77	81	83	85	..	..	..	60	69	80	86	91	94	96
2 1/2	..	..	..	51	59	69	75	79	82	85	..	..	..	57	66	78	85	89	93	95
2 5/8	..	..	..	48	57	68	74	78	81	84	..	..	..	54	64	76	83	88	92	94
2 3/4	..	..	..	..	55	66	73	77	81	83	..	..	..	52	62	74	82	87	91	93
2 7/8	..	..	..	..	53	65	72	76	[illegible]	[illegible]	..	..	..	49	59	73	81	86	90	93
8	..	..	..	..	..	..	..	..	..	50	..	..	..	..	..	..	..	..	..	56
8 1/4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	55
8 1/2	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	53
8 3/4	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	51
9	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	49

[a] In tabulating the sizes of shakes or checks, the rule used in approximating decimals by common fractions with 1/8-in. intervals has the effect of subtracting 1/64 in. from the size of each shake or check. For example, the strength ratios listed for a 3 1/2-in. shake or check are those that actually would obtain for a size of 3 31/64 in. In view of the allowance thus introduced and the fact that nominal instead of actual widths of face are used, the strength ratios in this table should be taken as maximum values.

[b] Ratios for sizes of shake or check other than those listed between 3 and 9 in. can be found by interpolation.

M 146 873

D 245-69 (1969)

[Par. 16.2, p. 159 permits shake size to vary in joist and plank only in relation to strength of green wood—a change from par. 16(b) of D 245-57T, even though par. 16.1, which recognizes a dry increase, remains the same.]

[Par. 23, p. 160, is essentially the same as D 245-57T for shear, modified for existence of D 2555-69.]

27.1 Strength ratios for various combinations of thickness of piece with size of shakes, checks, or splits are given in table 5. Strength ratios below 50 percent are not used (see 16.2). [p. 161]

[See the 1969 version of "Table 5" as abridged here.]

[Par. 63.1, p. 184, provides for seasoning increases for shear:]

. . . For these reasons, the modification of allowable unit stresses shown in Table 8 are applicable to lumber . . . The increases for horizontal shear apply only to lumber that is at these maximum moisture contents at the time of manufacture. [Increases shown in Table 8, p. 183, are 8 percent when the lumber maximum moisture content is 19 percent and are 13 percent when the maximum moisture content is 15 percent.]

A1. Formulas for Determining Strength Ratios Corresponding to Various Knot Sizes and Width of Face and to Sizes of Checks and Shakes for Beams and Stringers, Joists and Planks and Posts and Timbers.

Note A1—The strength ratios given in Tables 2, 3, 4, and 5 have been computed using the formulas given herein.

In the following formulas:

b = actual narrow face width, inch,
h = actual wide face width, inch,
k = knot size, inch,
w = check width, inch, and
S = strength ratio, percent

A1.4 Formulas for Strength Ratios Corresponding to Various Combinations of Size of Shake or Check and Thicknesses at End of Piece

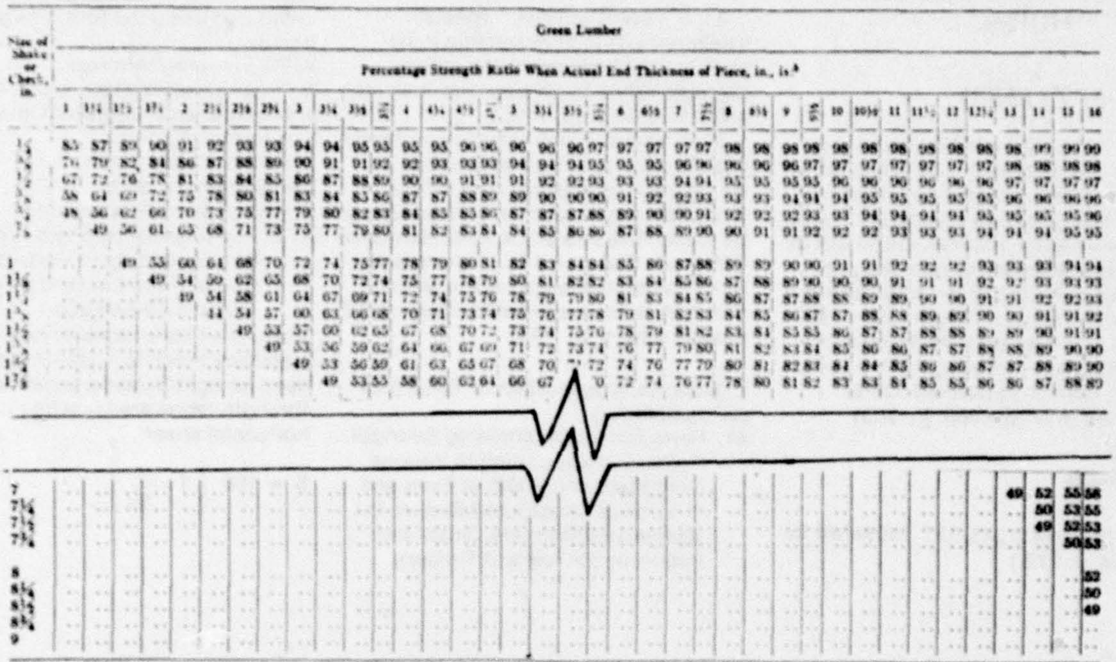


TABLE 5—STRENGTH RATIOS CORRESPONDING TO VARIOUS COMBINATIONS OF SIZE OF SHAKE OR CHECK AND THICKNESSES AT END OF PIECE[a]

NOTE—This table covers beams and stringers or joists and planks with shakes or checks in middle one half of height. Strength ratios are for stress in horizontal shear.

[a] The basic formulas for developing this table are given in Appendix A1.

[b] The strength ratio for any actual end thickness is obtained by linear interpolation from the tabulated values.

[p. 168]

Note A5—These formulas cover beams and stringers or joists and planks with shakes or checks in middle one half of height. Strength ratios are for stress in horizontal shear.

Limitations	Formula
b < 6 in.	$S = 100\left[1 - \dfrac{w - \frac{1}{24}}{b + \frac{3}{8}}\right]$
b ≥ 6 in.	$S = 100\left[1 - \dfrac{w - \frac{1}{24}}{b + \frac{1}{2}}\right]$

[p. 191]

D 245-70 (1971)

3.1.3 Strength ratios associated with shakes, checks, and splits are assumed to affect only horizontal shear in bending members. These strength ratios were derived, as for knots, by assuming that a critical cross section is reduced by the amount of the shake, or by an equivalent split or check. [p. 145]

[Par. 3.2.3 of D 245-70 is essentially the same as par. 27.1 of D 245-69 with the following added justification on 50 percent strength-ratio limit:]

3.2.3 . . . Strength ratios below 50 percent are not used, because a bending member that is split completely through lengthwise will still hold one half the shear load of an unsplit member. [p. 146]

[Slight wording change only for strength ratio formulas in par. A1.4 and Note A5, p. 167; seasoning increases remain the same as D 245-69.]

D 245-74 (1975)

[No change from D 245-70.]

Light Frame—Special Rules

D 245-57T (1958)

38(d). Where 2-inch dimension is to be used in light building construction in which the shear stress is not critical, a more liberal provision on end splits may be made. In such material, the length of an end split is limited to one and one-half times the width of the wide face in a grade with a shear strength ratio of 50 percent, or three-quarters of the width of the wide face in a grade with a shear strength ratio of 75 percent. Other grades are in proportion. [p. 203]

D 245-69

[Par. 38(d) of D 245-57T repeated as par. 36.4, p. 172.]

D 245-70 (1971)

3.2.3.1 Splits are given special treatment in 2-inch dimension to be used in light building construction. Strength ratios for this special case are given in table 6. [p. 146]

4.4.6 Where 2-inch dimension is to be used in light building construction in which the shear stress is not critical, a more liberal provision on end splits may be made. The size of the split, measured differently than in 4.4.2, is its average length along the length of the piece. Strength ratios are given for this special case in table 6. [p. 149]

[Note the reproduction of Table 6 as abridged here.]

A1. Formulas for Determining Strength Ratios Corresponding to Various Knot Sizes and Width of Face and to Sizes of Checks and Shakes for Beams and Stringers, Joists and Planks and Posts and Timbers

Note A1—The strength ratios given in tables 2, 3, 4, 5, and 6 have been computed using the formulas given herein.

In the following formulas:

b = actual narrow face width, inch,
h = actual wide face width, inch,
k = knot size, inch,
w = check width, inch,
l = split length, and
S = strength ratio, percent

A1.5 Formulas for Strength Ratios Corresponding to Various Combinations of Split Size and Width of Wide Face

Note A6—This formula covers bending members 2 inch in nominal thickness used for light building construction. Strength ratios are for stress in horizontal shear.

$$S = 100\left[1 - \frac{l}{3h}\right]$$

[p. 161]

TABLE 6 Strength Ratios for Horizontal Shear Corresponding to Split Size in Light Construction Bending Members.

Length of Split, in.[a]	Percentage Strength Ratio When Actual Width of Wide Face, in., is[a]																																			
	2	2¼	2½	2¾	3	3¼	3½	3¾	4	4¼	4½	4¾	5	5¼	5½	5¾	6	6½	7	7½	8	8½	9	9½	10	10½	11	11½	12	12½	13	13½	14	14½	15	15½	16
¼	96	96	97	97	97	97	98	98	98	98	98	98	98	98	98	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
⅜	94	94	95	95	96	96	96	97	97	97	97	97	98	98	98	98	98	98	98	98	98	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99	99
½	92	93	93	94	94	95	95	96	96	96	96	96	97	97	97	97	97	97	98	98	98	98	98	98	98	98	98	99	99	99	99	99	99	99	99	99	99
⅝	90	91	92	92	93	94	94	94	95	95	95	96	96	96	96	96	97	97	97	97	97	98	98	98	98	98	98	98	98	98	98	98	99	99	99	99	99
¾	88	89	90	91	92	92	93	93	94	94	94	95	95	95	95	96	96	96	96	97	97	97	97	97	98	98	98	98	98	98	98	98	98	98	98	98	98
⅞	85	87	88	89	90	91	92	92	93	93	94	94	94	94	95	95	95	96	96	96	96	97	97	97	97	97	97	97	98	98	98	98	98	98	98	98	98
1	83	85	87	88	89	90	90	91	92	92	93	93	93	94	94	94	94	95	95	96	96	96	96	96	97	97	97	97	97	97	97	98	98	98	98	98	98
1⅛	81	83	85	86	88	88	89	90	91	91	92	92	93	93	93	93	94	94	95	95	95	96	96	96	96	96	97	97	97	97	97	97	97	97	98	98	98
1¼	79	81	83	85	86	87	88	89	90	90	91	91	92	92	92	93	93	94	94	94	95	95	95	96	96	96	96	96	97	97	97	97	97	97	97	97	97
1⅜	77	80	82	83	85	86	87	88	89	89	90	90	91	91	92	92	92	93	93	94	94	95	95	95	95	96	96	96	96	96	96	97	97	97	97	97	97
1½	75	78	80	82	83	85	86	87	88	88	89	89	90	90	91	91	92	92	93	93	94	94	94	95	95	95	95	96	96	96	96	96	96	97	97	97	97
1⅝	73	76	78	80	82	83	85	86	86	87	88	89	89	90	90	91	91	92	92	93	93	94	94	94	95	95	95	95	95	96	96	96	96	96	96	97	97
1¾	71	74	77	79	81	82	83	84	85	86	87	88	88	89	89	90	90	91	92	92	93	93	94	94	94	94	95	95	95	95	96	96	96	96	96	96	96
1⅞	69	72	75	77	79	81	82	83	84	85	86	87	88	88	89	89	90	90	91	92	92	93	93	93	94	94	94	95	95	95	95	95	96	96	96	96	96
8														49	52	54	56	59	62	64	67	69	70	72	73	75	76	77	78	79	79	80	81	82	82	83	83
8¼															50	52	54	58	61	63	66	68	69	71	73	74	75	76	77	78	79	80	80	81	82	82	83
8½															48	51	53	56	60	62	65	67	69	70	72	73	74	75	76	77	78	79	80	80	81	82	82
8¾																49	51	55	58	61	64	66	68	69	71	72	73	75	76	77	78	78	79	80	81	81	82
9																	50	54	57	60	63	65	67	68	70	71	73	74	75	76	77	78	79	79	80	81	81

[a] Ratios corresponding to other split sizes and face widths can be found by linear interpolation.

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Evolution of allowable stresses in shear for lumber, by Robert L. Ethington, William L. Galligan, Henry M. Montrey, and Alan D. Freas. General Technical Report FPL 23, FPL, Forest Service, U.S. Department of Agriculture. 19 p. Madison, Wis.

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